NPS-GSBPP-05-006

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

A Decision Support Model for Valuing Proposed Improvements in Component Reliability

30 June 2005

by

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Prepared for: NAVSEA, PEO IWS, PEO SHIPS and
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The Acquisition Chair, Graduate School of Business & Public Policy, Naval Postgraduate School supported the funding of the research presented herein.

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REPORT DOCUMENTATION PAGE	Form approved OMB No 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE 30 JUNE 2005	3. REPORT TYPE AND DATES COVERED 1 OCTOBER 2004 – 30 JUNE 2005

4. TITLE AND SUBTITLE **A Decision Support Model for Valuing Proposed Improvements in Component Reliability**	**5. FUNDING** NPS ACQN Chair, NAVSEA, PEO SHIPS, PEO IWS
6. AUTHOR (S) **Keebom Kang, Associate Professor, Naval Postgraduate School** **Michael Boudreau, Senior Lecturer, Naval Postgraduate School** **Uday Apte, Professor, Naval Postgraduate School**	
7. PERFORMING ORGANIZATION NAME (S) AND ADDRESS (ES) NAVAL POSTGRADUATE SCHOOL GRADUATE SCHOOL OF BUSINESS AND PUBLIC POLICY 555 DYER ROAD MONTEREY, CA 93943-5103	**8. PERFORMING ORGANIZATION REPORT NUMBER** **NPS-GSBPP-05-006**
9. SPONSORING/MONITORING AGENCY NAME (S) AND ADDRESS (ES)	**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited	**12b. DISTRIBUTION CODE**

13. ABSTRACT (Maximum 200 words.)

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14. SUBJECT TERMS Reliability, Simulation Modeling, Life-Cycle Cost, Logistics support, Performance Based Logistics, Readiness Risk, Spares Inventory Levels, Total Ownership Cost (TOC)	**15. NUMBER OF PAGES** 25
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT: UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE: UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT: UNCLASSIFIED	20. LIMITATION OF ABSTRACT: UNLIMITED

NSN 7540-01-280-5800

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18

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Acknowledgements

We would like to acknowledge the support from the NAVSEA (Naval Sea Systems Command) PEO (Program Executive Officer) SHIPS and PEO IWS (Integrated Warfare Systems) for their funding. Authors also would like to thank Rear Admiral James Greene, USN (ret) for his support and funding arrangement for our research, and Ms. Karey Shaffer for her editorial support for this report.

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Keebom Kang, Associate Professor, joined the Naval Postgraduate School in 1988, where he teaches supply chain, logistics engineering and computer simulation modeling courses for the MBA program. His research interests are in the areas of logistics and simulation modeling in various military applications. He received his PhD in Industrial Engineering from Purdue University. Prior to joining NPS, he was on the faculty of the Industrial Engineering Department at the University of Miami, Coral Gables, Florida (1983-1988). He had held visiting professor positions at Syracuse University (Summer, 1985), Georgia Institute of Technology (Fall, 2003), Asia Institute of Technology in Thailand (Winter, 2004), and Pohang Institute of Science and Technology in Korea (Spring, 2004).

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EXECUTIVE SUMMARY

Providing reduced life-cycle cost and, at the same time, improving operational availability are fundamental goals of the Performance Based Logistics (PBL) and other logistics initiatives of the U.S. Department of Defense. In many PBL contracts, the contractual arrangements are typically stipulated at the level of individual components (such as a fuel cell) or a logistic element (such as inventory of certain spare parts). While achieving component level performance goal is certainly important, what really matters to a war fighter is the operational availability of the weapon system. Hence, there is a need to develop a methodology and an apparatus for estimating the operational availability (Ao) of a weapon system based on the component–level reliability and maintainability data. This current research is aimed at this need.

Specifically, we present two spreadsheet models and one discrete-event simulation model using Arena simulation language. The first model primarily supports life cycle cost calculations, but ignores the interactions among reliability, time to repair, and operational availability. The second model, while it does address these basic interactions, does not consider the full range of life cycle costs. However, both the first and the second model are static – they can only support average case analyses and sensitivity analyses. The third model incorporates the interactions among reliability, time to repair and operational availability into a simulation model that can support a weapon system level risk analysis. In their current form, these models are developed as a proof-of-concept. That is, we are not presenting a research case involving field

data, but rather, demonstrating the potential methodology and a tool using hypothetical yet realistic data.

I. INTRODUCTION

The US Department of Defense is engaged in a number of management initiatives (related to weapon system logistics and support) intended to provide reduced lifecycle cost while simultaneously improving operational availability, Ao. Performance-based Logistics (PBL) is one such program that entails the establishment of a particular kind of contractual vendor-client relationship between a logistic-service provider and a weapon-system manager. The Quadrennial Defense Review mandated the DoD implement PBL in order to, "compress the supply chain and improve readiness for major weapons systems and commodities" (OSD, 2001, 56). A key aspect of PBL contracts is their outcome focus; the client organization is supposed to specify key performance goals and allow the vendor to determine the best way of obtaining those goals (ASN-RDA, 2003).

This paper will not re-examine the core questions of whether PBL works, or why it works, as those questions have been examined extensively elsewhere (e.g., Berkowitz et al., 2003). Rather, we take as our starting point the question of how best to value the desired outcomes of a PBL contract. After all, as contractual vehicles, the price of the services to be provided must be negotiated. Also, given a limited budget but a proactive program manager, there will always be more opportunities to improve logistical support for a weapon system than dollars available to fund those opportunities.

We assume that opportunities to improve logistics outcomes should be valued on the basis of the cost-effectiveness of those opportunities.[1] As in the private sector, the cost effectiveness of an opportunity (investment) is its mission-value-over-time (profit, in the case of the private sector) divided by its cost-over-time. It would thus be a mistake to take the cost differentials of various logistic service alternatives as a statement of value because cost in no way informs the value of that service to the weapon-system

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[1] Caplice and Sheffi (1994), in reviewing a panoply of logistics metrics, categorized metrics based solely on comparisons of inputs (such as cost comparisons) as *utilization* metrics, while they categorized comparisons of outputs per input (such as what we are calling cost-effectiveness) as *productivity* metrics. They made the point that utilization measures are usually related to process (as opposed to performance) management.

operator. Even if one is willing to assume that current expenditures are cost effective (and hence, any cost reduction would be even more cost effective), there is no way to assess one alternative against another without a direct measure of value; mere cost differentials ignore the fact that the alternatives may have different impacts on mission value.

We will further assume that the mission value of a logistical service is a function of weapon-system performance, as neither a weapon-system component (such as a fuel cell) nor a logistic element (such as spares inventory) can contribute to mission objectives except through the weapon system. From a warfighter's viewpoint, a weapon system is either capable of supporting a mission, or it is not. While a fuel cell may be a necessary condition for the system to be mission capable, it is not a sufficient condition.

Operational availability (Ao) is a primary metric used to determine the probability that a weapon system will be capable of supporting a mission. For example, in an aircraft squadron, Ao of 85% implies that an average of 85% of the aircraft will be available to fly in support of some mission objective. Goals are often stated for Ao levels, and mission planning must take Ao into account. Moreover, neither a warfighter nor a resource manager wanting to make contingency plans should be content with knowing the nominal (target) or the average Ao level. He or she should have a sense of the distribution of Ao around the target levels: the probability that Ao will fall below some critical level.

It is also possible to measure Ao for fuel cells, as well as aircraft; an improvement in Ao for the fuel cell will provide at least some marginal improvement in Ao for the aircraft. But, this improvement will not be one-to-one; large improvements in fuel-cell availability may yield only trivial improvements in aircraft availability, depending not only on the failure rate of the fuel cells, but on the performance and availability of all the other critical components of the aircraft. Likewise, better fuel-cell availability will reduce the risk that a particular weapon system will not be operational for a particular mission, but the magnitude of that risk reduction depends on the probability that all the other critical components of the aircraft are available.

Hence, the value of an improvement of *component* logistics can only be understood in terms of the performance of all the other critical components of a weapon system. Similarly, the value of an improvement in a single logistics element (such as spares inventory) can only be determined in conjunction with other key logistics elements.

The modeling approach we will outline in this paper has applicability beyond PBL. It is useful in understanding the value of component-level logistic services, or services directed at only a subset of logistic elements (inventory only, or depot-level repair only). However, we contend that an implementation of PBL that is fully consistent with the original intent of performance-based service acquisition *must* use an approach similar to the one we outline, because it is impossible to put a value (and, hence, a contract price) on those services without such an approach.

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II. LITERATURE REVIEW

While we are arguing for an assessment of value that will provide a more complete picture of the cost effectiveness of a PBL proposal (by providing a numerator to a productivity ratio), we recognize that an estimation of the lifecycle costs of such proposals is far from trivial. Outsourced logistic services for weapon systems are particularly difficult to cost; for example, the ongoing contract management (transaction) costs can be substantial, but are rarely measured (Domberger, Jensen & Stonecash, 2002).

We think such transaction costs are particularly important in light of a recent Government Accountability Office report (GAO, 2004) that was critical of systems-level PBL contracts; this document recommended greater emphasis on PBL contracts at the component level, especially for commodity-type components (which, according to the GAO, reflected "commercial best practices"). PBL contracts on commodities would be especially appealing because vendors providing commodities can expect to enjoy economies of scale that the DoD could not experience (as vendors would be able to offer those commodities across a broad population of users). These increased economies of scale would reduce the price of such services. Unfortunately, of course, aside from domestic transportation and depot-level spares for a relatively small set of components used commonly between defense and industry, the number of critical components (or logistics elements) of weapon systems that can be considered commodities is relatively small. For non-commodity items, a key economic consideration in out-sourcing is the increase in transaction costs entailed by dealing with an outside vendor (Gufstafson et al., 1996). Such costs increase substantially when one is offering a PBL contract at the component level. As we will show, aside from the additional burden of contract maintenance for many small contracts, the proper valuation and management of such component-level contracts entails the development of a comprehensive model which incorporates key performance dimensions of *all* critical components.

Perhaps in an effort to reduce such transaction costs, or perhaps in response to a complaint that PBL involved too many metrics, the Under Secretary of Defense for Acquisition, Technology and Logistics (USD-ATL, 2004) recently issued guidance for PBL metrics. While clearly indicating that PBL could be applied at the subsystem or major assembly level, the memo listed five key performance criteria: 1) *weapon system* operational availability, 2) *weapon system* operational reliability, 3) *weapon system* cost per usage, 4) logistics footprint for a *weapon system,* and 5) response time required for *weapon system* logistics support.

Of course, these measures are interrelated. We think the central non-cost measure is operational availability. The other three non-cost measures can all be seen in some ways as subsidiary to availability. Reliability (e.g., time to failure), footprint (e.g., number of spares and size of fielded or intermediate maintenance and repair facility) and response time (e.g., time to repair) are all critical determinants of availability. Yet, there may be good reasons to measure reliability, footprint and response time separately. For example, reliability affects not only availability, but also the probability of system failure in the field; likewise, footprint affects not only availability, but operational agility as well. However, operational availability in many ways summarizes reliability, response time and footprint. We will develop a model in the next section that demonstrates the precise interaction between time to failure, time to repair, and spare inventory levels. It also demonstrates how these variables determine availability. Thus, as they affect Ao, footprint, response time, and even reliability are all process and *not* performance measures. We will focus on availability (with the caveat that it may not be the sole determinant of value) because it is necessary to an understanding of value.

In specifying performance outcomes (but not processes) to a vendor, PBL contracts are deliberately designed to transfer some degree of operational and financial risk to a vendor (Doerr, Lewis & Eaton, forthcoming). As risk transfer is an intended outcome of the initiative, and as the risk of falling below a certain level of operational availability is an important performance dimension, it is clearly important to incorporate the risk associated with operational availability at the system level into a measure of value. From the warfighter's point of view, this risk may be the key performance

dimension (Eaton, Doerr & Lewis, forthcoming). The warfighter, after all, is less concerned with the average number of mission-capable aircraft than he is concerned with the probability that he will have enough aircraft to fly a particular mission. The procedure we will outline allows the assessment of a proposed logistics improvement not only on the *average* impact that improvement would have on the operational availability of the aircraft, but on the *risk* associated with the operational availability of the aircraft as well.

Weapon systems are, of course, the military's key capital assets related to operational capacity, and the logistics services in question can be seen as primarily affecting the level of operational capacity available to the warfighter. The sort of risk measurement we are proposing is increasingly recognized as central to the valuation of operational capacity of corporate assets in the private sector as well.

Assessments of risk/return profiles for capital assets are, of course, behind the recent work on Real Options (Mun, 2002). And in capacity planning in particular, the incorporation of risk into capacity models was listed in a recent literature review as a key area in which research was expected to develop (Van Miegham, 2003). Risk-based models have recently been applied to the acquisition of production capacity for airfoils used in military aircraft (Prueitt & Park, 2003). Mostly, risk-based capacity models deal with technological, demand, or price uncertainty, and are not directly applicable to the valuation of logistic services and the uncertain impact those services will have on system availability (capacity). The point we are making is that there is growing consensus that a proper valuation of capacity-related planning (such as the planning associated with offering a PBL contract) must include an assessment of risk.

In this paper we develop three models as decision-support systems (Keen & Morton, 1978; Power, 2002; Turban & Aronson, 1998). The term "decision-support system" implies use of computer-based systems to:

1. assist the warfighters in their decision process in semi-structured tasks,
2. support, rather than replace, the warfighter's judgment, and
3. improve the effectiveness of the practical decision-making process.

The dramatic improvements in computer power and software capability (such as spreadsheet and simulation models) allow convenient access to powerful decision-support systems for improved decision making. Making such models available as decision-support systems is the primary goal of this research.

III. MODELS

In this section, we present two spreadsheet models and one discrete-event simulation model using Arena simulation language (Kelton, 2004). The first model primarily supports lifecycle cost calculations but ignores the interactions among reliability, time to repair, and operational availability. The second model, while it does address these basic interactions, does not consider the full range of lifecycle costs. However, both the first and the second model are static—they can only support average case analyses and sensitivity analyses. The third model incorporates the interactions among reliability, time to repair and operational availability into a simulation model that can support a risk analysis, but which does not directly address lifecycle cost issues.

In their current form, these models are intended as a proof-of-concept only. That is, we are not presenting a research case involving field data; rather, we are demonstrating the potential of an approach using hypothetical data.

3.1. Spreadsheet Lifecycle Cost Model (Model 1)

Model 1 is a compressive lifecycle cost analysis model for a hypothetical UAV (unmanned aerial vehicle) case study intended as a proof-of-concept for our modeling approaches. This case study was adapted from Logistics Engineering class lecture notes at the Naval Postgraduate School (Kang, 2004). The complete case study is described in Appendix A, and the spreadsheet model is available from http://web.nps.navy.mil/ ~mn4310/UAV_Model_1.xls.

This model computes the total system lifecycle cost for major weapon systems from R&D to deployment to phase-out. The lifecycle cost includes research, development, test and evaluation, acquisition, production, operations and maintenance, and phase-out costs. This model is a comprehensive decision-support tool for program managers. The model can be used to establish the baseline total ownership cost of major weapon systems during the planning, as well as operations, stages. The user can conduct sensitivity analyses on various input parameters such as reliability, manning, training, and R&D cost. As the user changes any of the parameters, the model immediately updates the total lifecycle cost, so the user can see the financial

impact of input parameter changes in the long-run. We suggest the reader download the spreadsheet model and change some of the parameters in the “INPUT” worksheet.

3.2. Revised Spreadsheet Model (Model 2) and Simulation Model (Model 3)

A shortcoming of the spreadsheet model (Model 1) is that it cannot analyze the dynamic relationship between reliability and operational availability. For example, deterioration in reliability of a certain component will decrease the system’s operational availability. At the same time, the workload at a repair shop will increase, forcing the repair turnaround time to become longer, which in turn will decrease the operational availability of the system. In Model 1, the average repair turnaround time remains the same regardless of the changes in component reliability.

To overcome this limitation, we have developed a discrete-event simulation model (Model 3) that can be used along with a revised spreadsheet model (Model 2). Model 2 is essentially derived from Model 1. It is a small-scale spreadsheet model designed to focus on reliability and maintainability. Given logistics input parameters (see Figure 1), Model 2 computes spare-parts requirements, inventory, transportation and repair costs followed by the total maintenance costs over the lifecycle of the system. Model 2 does not consider R&D cost or infrastructure costs. It only considers variable costs while operating the weapon system. Figure 2 shows the total lifecycle maintenance cost of $442,656,976 based on the input parameters in Figure 1. To demonstrate how Model 2 could be used, suppose we improve the MTBF of the main display unit from 1,500 hours to 2,000 hours. The total cost will then be decreased to $440,319,492, representing approximately $2.3 million savings in maintenance cost. This is valuable information for the program manager when s/he makes the component-reliability improvement decisions.

Figure 1. Input Parameter for Model 2

No of Squadrons	4			
No of UAV systems per squadron	10			
No of Air Vehicles per system	4			
No of Ground Control stations per system	2			
Ground Equip Monthly Op Hrs Hours	300	hrs		
AV Flying Hours/Vehicle/month	120	hrs		
AutoLand & Launch/RecMonthly Op Hours	60	hrs		
Repair Turnaround Time	10	days		
Protection Level for Critical Components	0.95			
Protection Level for non-Critical Components	0.85			
Hourly charge for repair including material cost	$500			
Transportation cost per failure	$200			
Annual Inventory rate	21%			
Capital Discount rate	10%			
Lifecycle	20	years		
Ground Control Station Components	MTBF		Unit Cost	
Main Display Unit	1000	0.00100	$ 500,000	Critical
Power Supply	4000	0.00025	$ 400,000	Critical
Power Gen	3500	0.00029	$ 300,000	Critical
Air Conditioner	6000	0.00017	$ 400,000	Critical
Guidance & Control	500	0.00200	$ 400,000	NonCritical
Other Ground Equip	MTBF		Unit Cost	
Launch & Recovery System	500	0.00200	$ 1,200,000	Critical
AutoLand System	1000	0.00100	$ 2,000,000	NonCritical
Data Terminal	3000	0.00033	$ 1,000,000	NonCritical
AV	MTBF		Unit Cost	
Navigation/Avionics	1000	0.00100	$ 200,000	Critical
Engine	500	0.00200	$ 100,000	Critical
Propeller	500	0.00200	$ 50,000	Critical
Video Scanner	2500	0.00040	$ 150,000	NonCritical
IR Scanner	450	0.00222	$ 150,000	NonCritical
IR Data-Link	800	0.00125	$ 200,000	NonCritical

Figure 2. Sample Output of Model 2

Annual Spare Inventory Cost	$ 2,688,000	per squadron
Annual Repair Cost	$ 8,800,857	per squadron
Annual Transportation cost	$ 328,034	per squadron
Total cost per squadron per year	$ 11,816,891	
Total Annual cost	$ 47,267,566	
Total Lifecycle Cost	$442,656,976	

Once the cost analysis is completed (using Model 2), the same input parameters are used for the simulation model (Model 3) to estimate the operational availability and other performance measures of the system (e.g., probability that the operational availability falls below some critical level). Model 2 and Model 3 (simulation model) complement each other.

3.3. Simulation Scenarios

In this simulation model (Model 3), we only consider the critical components (engine, propeller, avionics computer) for a squadron of 10 UAV systems with 40 air vehicles (see Appendix A). When one of these critical components fails, the faulty component is removed from the air vehicle, and an RFI (ready-for-issue) spare is installed. The faulty component is sent to the repair shop to be fixed. After repair, it becomes an RFI spare. When a critical component fails, and an RFI spare is not available, the air vehicle will be grounded (and will become not-mission capable, or NMC) until an RFI component is available. A failure of non-critical components may degrade readiness, but the system is assumed to be operable (that is, mission capable or MC).

The input parameters—such as MTBF and number of spares for each component, repair times (in hours), transportation delay (one way, in days)—are read from the spreadsheet (see Figure 3). When a component fails in Scenario 1, it requires 9 days (4.5 days one way) of transportation delay with 10 hours of repair work; this work follows a triangular distribution with a mode of 10 hours, an upper limit of 50% above

the mode (i.e., 15 hours) and a lower limit of 50% below the mode (i.e., 5 hours). The waiting time at the repair shop, if any, is estimated inside the simulation. The repair time of 10 hours and the transportation delays of 9 days (4.5 day each way) in Figure 1 f approximate the total repair TAT of ten days in Scenario 1.

Figure 3. Simulation Input Spreadsheet

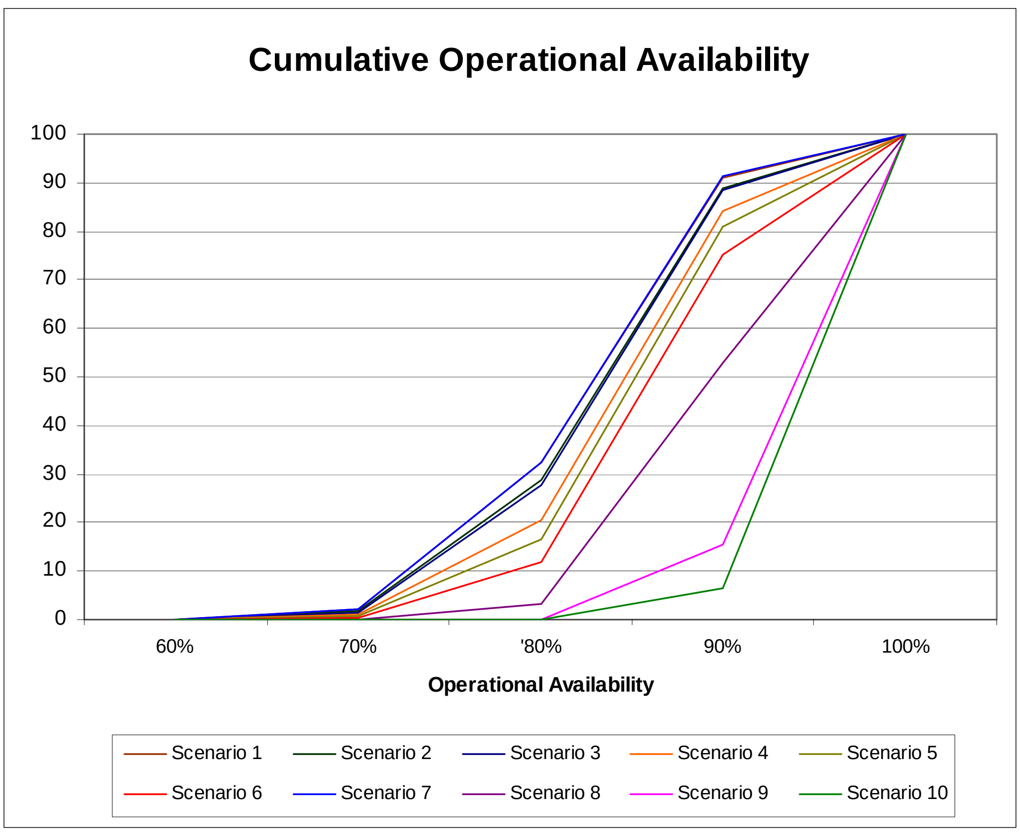
Scenario	MTBF_ Eng	MTBF_ Prop	MTBF_ AvComp	Spare Engines	Spare Props	Spare AvComps	Eng Repair hrs	Prop Repair hrs	AvComp Repair hrs	Trans Delays (Days)
1	1000	500	500	4	6	6	10	10	10	4.5
2	1250	500	500	4	6	6	10	10	10	4.5
3	1500	500	500	4	6	6	10	10	10	4.5
4	1000	750	500	4	6	6	10	10	10	4.5
5	1000	1000	500	4	6	6	10	10	10	4.5
6	1500	1000	500	4	6	6	10	10	10	4.5
7	1000	500	500	10	10	10	10	10	10	4.5
8	1000	500	500	4	6	6	10	10	10	2.25
9	1000	500	500	4	6	6	10	10	10	1
10	1500	1000	500	4	6	6	10	10	10	1

Given the input parameters in Figure 3, Model 3 simulates each scenario over 1,000,000 hours. Multiple scenarios can be executed in one simulation run (e.g., 10 in this case). The results captured for each scenario are the average operational availability (Ao) for the air vehicles in the squadron, along with the cumulative distribution of operational availability. These results are tabulated in Figure 4. The cumulative distribution of operational availability is also depicted graphically in Figure 5.

Figure 4. Simulation Output: Cumulative Operational Availability and the Average Operational Availability for Each Scenario

Cumulative Operational Availability											Avg Op Av
	10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**	
1	0.00	0.00	0.00	0.00	0.00	0.02	2.27	32.25	90.91	100.00	0.837
2	0.00	0.00	0.00	0.00	0.00	0.01	1.68	28.76	88.99	100.00	0.843
3	0.00	0.00	0.00	0.00	0.00	0.01	1.50	27.53	88.47	100.00	0.845
4	0.00	0.00	0.00	0.00	0.00	0.01	0.95	20.50	84.35	100.00	0.857
5	0.00	0.00	0.00	0.00	0.00	0.00	0.55	16.50	80.87	100.00	0.865
6	0.00	0.00	0.00	0.00	0.00	0.00	0.22	11.70	75.25	100.00	0.876
7	0.00	0.00	0.00	0.00	0.00	0.04	2.27	32.43	91.39	100.00	0.837
8	0.00	0.00	0.00	0.00	0.00	0.00	0.03	3.14	52.74	100.00	0.906
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	15.37	100.00	0.948
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	6.63	100.00	0.962

Figure 5. Cumulative Operational Availability



Let's assume that the commander's goal is to maintain an average Ao of 85%. He also knows his mission capability will be critically jeopardized if Ao falls below 80%. Therefore, he wants to estimate the probability that this event (maintaining the average Ao to be above 85%) might happen. The results in Figure 4 show that the average Ao of Scenario 1 is 83.7% (the last column of Scenario 1) and the probability of Ao falling to 80% or below is 32.25% (the 9th column with a heading of 80% for Scenario 1). Scenario 1 is not acceptable to the commander since the average Ao is below his goal, and the probability of Ao falling below 80% seems to be too high. He can generate more scenarios (e.g., Scenarios 2 through 10) to assess the impact of changes in component reliability or logistics elements (spare parts, repair and transportation times) on the entire system-level Ao.

In Scenarios 2 and 3, the MTBF of an engine is increased from 1,000 hours to 1,250 and 1,500, respectively. In Scenarios 4 and 5, the MTBF of a propeller is improved from 500 hours to 750 and 1,000, respectively. Improvement in Ao can be observed from the far right-hand side column of the Figure 4. Changes in Scenarios 4 and 5 are preferred to those of Scenarios 2 and 3. In Scenario 6, the MTBFs of both the engine and propeller are increased respectively to 1,500 and 1,000. The overall Ao is increased to 87.6% (from 83.7% of Scenario 1), and the probability of Ao falling below 80% has substantially reduced to 11.7% (from 32.25%). Increase in spare parts (Scenario 7) does not improve the performance at all. However, significant reduction in transportation time (Scenario 8) improves the system performance. In Scenarios 8 and 9, when the transportation delays are reduced from 4.5 days to 2.25 and 1 respectively, Ao jumps to 90.6% and 94.8%, respectively; likewise, the probabilities of Ao falling below 80% drop to 3.14% and 0.08%, respectively. The Scenario 10 is the same as Scenario 9 except that the MTBFs of an engine and a propeller are increased to 1,500 and 1,000, respectively. Ao hits 96.2% with the probability of Ao falling below 80% now negligible (0.02%).

The parameters in Scenarios 2 through 10 can be input to Model 2 to compute the total maintenance cost for each scenario. For example, by entering the parameters from Scenario 10 into Model 2 in Figure 2, a PM will note results in a total lifecycle

maintenance cost of $375,712,781 (i.e., savings of approximately $120 million over the base case of Scenario 1). Scenario 10 provides an Ao 12.5% higher than Scenario 1 (from 83.7% to 96.25%) with the risk of Ao falling below 80% becoming a non-issue.

Models 2 and 3 can potentially serve as a communication tool between the budget community and warfighters. When reliability improvements are made on several components in a complex system, the warfighter’s primary concern is readiness, or Ao, while the budget analysts’ focus is on financial implications. These two models provide valuable solutions to both communities.

IV. SUMMARY

Providing reduced lifecycle cost and, at the same time, improving operational availability are fundamental goals of the Performance-based Logistics (PBL) and other logistics initiatives of the US Department of Defense. In many PBL contracts, the contractual arrangements are typically stipulated at the level of individual components (such as a fuel cell) or a logistic element (such as inventory of certain spare parts). While achieving component-level performance goals is certainly important, what really matters to a warfighter is the operational availability of the weapon system. Hence, there is a need to develop a methodology and an apparatus for estimating the operational availability (Ao) of a weapon system based on the component-level reliability and maintainability data. This current research is aimed at this need.

Specifically, we present two spreadsheet models and one discrete-event simulation model using Arena simulation language. The first model primarily supports lifecycle cost calculations, but ignores the interactions among reliability, time to repair, and operational availability. The second model, while it does address these basic interactions, does not consider the full range of lifecycle costs. However, both the first and the second models are static—they can only support average case analyses and sensitivity analyses. The third model incorporates the interactions among reliability, time to repair and operational availability into a simulation model that can support a weapon-system-level risk analysis. In their current form, these models are developed as a proof-of-concept. That is, we are not presenting a research case involving field data, but rather are demonstrating the potential methodology and a tool using hypothetical, yet realistic, data.

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VI. APPENDIX: Unmanned Aerial Vehicle (UAV) Case Study

A UAV system consists of four air vehicles (AV's), two ground-control stations (GCSs), modular mission payloads (MMPs), data links, remote data terminals (RDTs) and an automatic landing system. A total of 8 squadrons (two squadrons in each coast of CONUS, and one each for Pacific, Indian, Mediterranean, and Atlantic Oceans) will be established to accommodate the new system. Each squadron will have its own intermediate-level maintenance capabilities. Each squadron will have 10 VTUAV systems. Detachment personnel (for each UAV system) will consist of three officers (one OIC and two mission officers), three Chief Petty Officers (CPOs) and 12 enlisted. I-Level Maintenance personnel will consist of one officer, one Chief petty officer and ten enlisted. Squadron headquarters personnel will be made up of seven officers, ten CPOs and twenty enlisted. Composite costs for personnel are estimated as follows: Officer—$140,000 per year, CPO—$115,000 per year, Enlisted—$70,000 per year.

Production begins in Fiscal Year 2004, with all VTUAV's scheduled for field tesing in the year following their production. A total of 80 VTUAV systems will be produced; the lifecycle of the program is estimated to be 30 years (2005-2034). The risk of loss of an AV in peace time is 2-7% per year, while the risk of loss of an AV in operation during a contingency is 15-30% per year. A chance of a contingency during the lifecycle of the program is 15% per year. Lost AVs will be replaced the next year. However, no orders for replacement AVs will be placed in the last 5 years of the lifecycle (i.e., YR 2029 – 2034). We are assuming by then new UAV systems will gradually replace the current ones.

Research and development costs are $15 million for FY 01, $20 million in FY 02 and $50 million in FYs 03 and 04. The marginal production cost of AV (with payload) is $1 million. The cost of maintaining a production capability throughout the life of the system is $12 M per year for every year any aerial vehicles are produced. Thus, the annual production cost of AV is $12M + $1M * (# of AV produced). Ground-Control

Equipment, which consists of two GCSs, RDTs, test equipment and an automatic landing system, will cost $20 million per system. The I-level operating cost is $6 million/yr per I-level plus an additional one-time capital investment of $25 million (including installation of test equipment) prior to the year of operation. A capital discount rate of 10%/yr and the inflation rate of 4%/yr will be used.

Billet requirements are based on all personnel fully qualified/current/certified to perform all missions/Navy Enlisted Classification Code (NEC)/Military Occupational Specialty (MOS). Operators are required to have functional applications of the use and control of the UAV, and will be trained in operation of all aspects of the UAV navigation, launch flight control and recovery. Officers and CPOs will attend additional training on preflight planning, mission profile construction and UAV tactical-intelligence integration. Costs for the training will be $1,600/person/week for the basic training and $3,000/person/week for the advanced training. An attrition rate of 25% per year is used after the first year, including personnel rotation. Required training is as follows:

<u>Detachment personnel</u>

- Basic UAV Training (Officers, CPOs, junior enlisted): 10 weeks
- Advance Training (Officers and CPOs only): 5 weeks

<u>I-Level Maintenance personnel</u>

- Basic Maintenance Training (Officers, CPOs, junior enlisted): 20 weeks
- Advance Maintenance Training (Officers and CPOs only): 5 weeks

<u>Squadron Headquarters personnel</u>

- Basic UAV intelligence course (Officers, CPOs, junior enlisted): 10 weeks
- Advance Training (Officers and CPOs only): 5 weeks

Spare parts management will be consolidated at the I-Level on a one-for-one exchange. We will assume that the transportation cost is $100 per shipment (i.e., $200 per failure). Spares replacement and repair materials cost will be equal to 50% of the value of spares per year. Sparing levels will be as follows: critical units—95% and non-critical units—85%. Maintenance turnaround time (TAT), including transportation

delays, for I-Level is 10 days and D-Level is 40 days. It is assumed that 80% of failures can be repaired at the I-Level (thus 20% at the D-level). Spare-level calculations are based on "t =10 (0.8) + 40 (0.2) = 16 days." D-Level cost is estimated to be $5,000 per repair including the transportation costs. Ground equipment is expected to operate 300 hours per month; the AV flying hour is estimated at 120 hours per month per vehicle. The launch/recovery and the auto-landing systems are used 20% of the time the ground-control station is in operation (i.e., 60 hours per month). POL (petroleum, oil and lubricant) costs are estimated at $60 per flight hour. The MTBF of each component, its cost, and the required protection level (customer service level) are included as follows:

	MTBF	Cost	Criticality
I. Ground Station (2 per VTUAV system)			
Main Display Unit	1,500 hrs	$ 500,000	critical
Power Supply	4,000 hrs	$ 400,000	critical
Power Generator	3,500 hrs	$ 300,000	critical
Air Conditioner	6,000 hrs	$ 400,000	critical
Guidance & Control	500 hrs	$ 400,000	non-critical
II. Other Ground Equipment (1 per VTUAV system)			
Launch/Recovery System	500 hrs	$1,200,000	critical
Auto-landing System	1,000 hrs	$2,000,000	non-critical
Data Terminal	3,000 hrs	$1,000,000	non-critical
III. AV and Payload			
Engine	500 hrs	$ 100,000	critical
Propeller	500 hrs	$ 50,000	critical
Navigation/avionics	1,000 hrs	$ 200,000	critical
Video Scanner	2,500 hrs	$ 150,000	non-critical

IR Scanner	450 hrs	$ 150,000	non-critical
IR Data-Link	800 hrs	$ 200,000	non-critical

The System activation/deactivation plan is as follows:

System Activation plan:	FY 2005 - 20 systems
(2 squadrons at a time)	FY 2006 - 20 systems
	FY 2007 - 20 systems
	FY 2008 - 20 systems

System Deactivation:	FY 2031 - 20 systems
(phase-out) plan	FY 2032 - 20 systems
(2 squadrons at a time)	FY 2033 - 20 systems
	FY 2034 - 20 systems

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